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Costain, Phillip Atkinson

Monterey, California; Naval Postgraduate School

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PHILLIP ATKINSON COSTAIN

United States
Naval Postgraduate School



# THESIS

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by

Phillip Atkinson Costain
Major, United States Army
B.S., United States Military Academy, 1962

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ABSTRACT

This experiment was a road test of a combined brake-accelerator pedal conducted at Laguna Seca Raceway, Monterey, California. One purpose was to compare the results of the road test with previous results of laboratory experiments at the Naval Postgraduate School, Monterey, California. Another purpose was to investigate the effect of moderate speeds and road conditions on brake reaction times.

A total of 13 test subjects were used, from 28 to 43 years of age, each contributing 40 reaction times during approximately 16 miles of driving. The combined brake pedal and the conventional brake pedal resulted in average reaction times of .302 seconds and .470 seconds, respectively, significant at the .01 level. Compared to the most recent laboratory tests the conventional pedal results were almost identical. Results with the combined brake-accelerator pedals were significantly slower. Although slower, the savings in brake reaction time during the road test of .168 second is a 36% reaction time savings which, translated into distance, is approximately 15 feet at 60 miles per hour. Speeds and road conditions were not significant at the .01 level of significance.

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ACKNOWLEDGMENT

Research projects of this type require a great deal of design effort and specialized talent which involve the skills of many individuals. In addition the use of a facility such as the Laguna Seca Raceway involves extensive cooperation and coordination of the people responsible.

First, the author is indebted to Dr. Gary K. Poock, his thesis advisor, for his guidance, assistance and encouragement. Second, the author is indebted to previous students whose efforts led to this project; to Michael O'Dea and his assistants at the machine facility; to Mr. Robert Smith and his assistant at the electronics laboratory; and to Mr. James M. LeVine of the transportation motor pool, all of whose advice, assistance, and talents were instrumental in the successful completion of this project. Third, the author acknowledges the cooperation and assistance of Mr. Robert S. Hugill, Business Manager of the Sports Car Racing Association of the Monterey Peninsula and Colonel Edwin C. Pittenger, Jr., Comptroller at Fort Ord, California, in making available the Laguna Seca Race Track as the testing site.

Lastly, the author must thank the test subjects who spent considerable time and effort in traveling to the test site and participating in the experiment.

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# I. INTRODUCTION

The National Traffic and Motor Vehicle Safety Act of 1966 was one of the recent important steps forward to improve the safety of automobiles. The National Highway Traffic Safety Administration under the direction of Douglas Toms is the major agency setting guidelines for new safety standards. The standards are resulting in crash programs in the United States Automobile Industries to meet prescribed deadlines. (Business Week, 27 February.)

Increased public awareness and Congressional interest in safety has been prompted in part by books such as consumer advocate Ralph Nader's Unsafe at Any Speed, and its resulting publicity. In light of the increased awareness to automobile hazards, research sponsored by the United States Government is being emphasized. The Transportation Department has released two contracts to Fairchild Hiller Corporation and AMF, Incorporated, amounting to over seven million dollars for the development of an Experimental Safety Vehicle. Among other things, "improved braking" is one of the specifications (Business Week, 27 February 1971). Anti-skid braking systems, which minimize stopping distance once brakes are applied, have already been developed and are an option on some higher priced vehicles. However, these systems do not reduce the time necessary to apply the brakes. This reaction time and an effort to minimize it will be the subject of the paper.

# II. BACKGROUND

## A. LITERATURE

A considerable amount of literature is available on the development of car braking systems, brake reaction times and the search for the optimal design of brake pedals. The most appropriate literature dealing with the single foot pedal and the historical development of the brake-accelerator pedal up to mid-1970 is well documented by J. P. T. Sullivan [8] and will not be repeated here. In addition, appropriate recent literature bearing directly on the experiment not mentioned by Sullivan [8] will be included in the body of this paper.

## B. DEFINITIONS

The following definitions apply to this experiment and discussions of other past experiments.

### 1. Reaction Time

Reaction Time is defined as the sum of two components.

a. Non-movement time: the time required to sense and determine what response to make.

b. Movement time: the time required to physically respond to the signal in order to initially depress brake pedal.

### 2. Floor Angle

The angle between the surface of the combined pedal and the floor of the apparatus to which the pedal is attached, i.e., the car floor or the laboratory apparatus floor which is parallel to the ground.

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3. <u>Rotational Angle</u>

The angle between a vertical mid-saggital plane through the body and the side of the combined brake-accelerator pedal.

4. <u>Ankle Angle</u>

The angle between the sole of the foot and the line between the lateral malleolus (outer ankle bone) and the styloid process.

## III. PROBLEM

Three experiments have been conducted at the Naval Postgraduate School over the past two years dealing with a combined brake-accelerator pedal. Each of these experiments has resulted in suggestions for improving the reaction time of drivers in an emergency stopping situation, but all have been conducted in the laboratory environment. The first experiment conducted by A. E. West [11] compared a single pedal of hinged design and a single pedal of one piece design, of which the latter proved to be the fastest integrated brake-accelerator design. The second experiment conducted by T. J. Toben [10] utilized the one piece pedal design from A. E. West's research and investigated whether reaction time changed significantly with changes in angular position of a combined pedal. It was found that $55^{\circ}$ floor angle and $0^{\circ}$ rotational angle, $55/0^{\circ}$, resulted in the fastest mean reaction time. This position was significantly better than all other positions except for $55^{\circ}$ floor angle and $15^{\circ}$ rotational angle, $55^{\circ}/15^{\circ}$. The third experiment, run by J. P. T. Sullivan [8], made a direct comparison of a conventional brake system, an American Automobile Association (AAA) device, and the new dual function pedal developed during the first experiment. He also introduced a new variable of seat tilt. His results showed at $55^{\circ}$ floor angle and $10^{\circ}$ rotational angle (note this lies between $55^{\circ}/0^{\circ}$ and $55^{\circ}/15^{\circ}$ found to be optimal by T. J. Toben [10])that seat tilt did not affect reaction time. Although all aspects of a single brake-accelerator pedal were not investigated in these experiments it was felt that the results to date needed a real environment test, i.e., a road test, incorporating

[illegible]

what had been established to date. Therefore this experiment was to apply what had been learned in the laboratory to the road and compare it with an existing car braking system. In addition it was to check the laboratory results with the road test results and investigate whether changes in road condition and/or moderate speed effected brake reaction times.

## IV. THE EXPERIMENT

### A. PURPOSE

This experiment was designed to obtain brake reaction time data for two different braking systems at two moderate speeds, 25 miles per hour and 35 miles per hour and five road conditions, downhill, uphill, curve left, curve right, and straightaway.

### B. THE APPARATUS

The test vehicle was a 1964 Navy Sedan (Figure 1). It had a push-button automatic transmission, conventional brakes, a foot pedal emergency brake, and a conventional seat adjustment to move the seat forward and backward.

The sedan was modified in four ways. One, the front seat had the right side removed, except for the structural framework, to provide space for timing apparatus and associated equipment. Second, a hole was cut in the fire wall to provide space for the brake-accelerator pedal. Third, the muffler system was modified forward of the hole in the fire wall to provide additional space for the combined pedal. Lastly, a shoulder strap was installed on the driver's side.

The one-piece combined pedal tested by West [11] and Toben [10] as modified by Sullivan [8] was selected for use in the sedan. The solid pedal, which was 3.5 inches wide, was changed in several ways in order to fit the physical limitations of the test vehicle. First, the rounded one-half inch high plate that was placed as a

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FIGURE 1. Test Vehicle

heel support was lowered by one inch to insure that subjects with larger shoes would not hit the heater on the underside of the dash with their toes. The plate served as a resting place for the subject's heel so he would not have to exert force to hold his foot on the pedal during testing. Second, the accelerator shaft was two inches from the front edge of the pedal rather than three inches and the pedal pivoted about the braking shaft 2.5 inches forward of the heel support rather than 1.25 inches. This results in 6.25 inches between the two shafts (Figure 2).

The pedal was made out of aluminum and had a non-slip rubber strip on its face. A spring of 18 pounds per inch on the braking shaft under the heel provided a force against accidental depression of the shaft. A conscious muscular effort was required to overcome the spring. A light spring on the accelerator shaft provided a return to idle position.

The pedal used in the laboratory in the previous experiments simulated disengagement of the accelerator when the braking shaft was depressed one-sixteenth of an inch. The pedal used in the car was designed to physically disengage from the car's accelerator linkage when the braking shaft under the subject's heel was depressed one-sixteenth of an inch. This was accomplished by two rack gears which, when the braking shaft was not depressed, linked the accelerator cable and, when the braking shaft was depressed one-sixteenth of an inch or more, separated the gears and therefore the accelerator linkage (Figures 3 and 4).

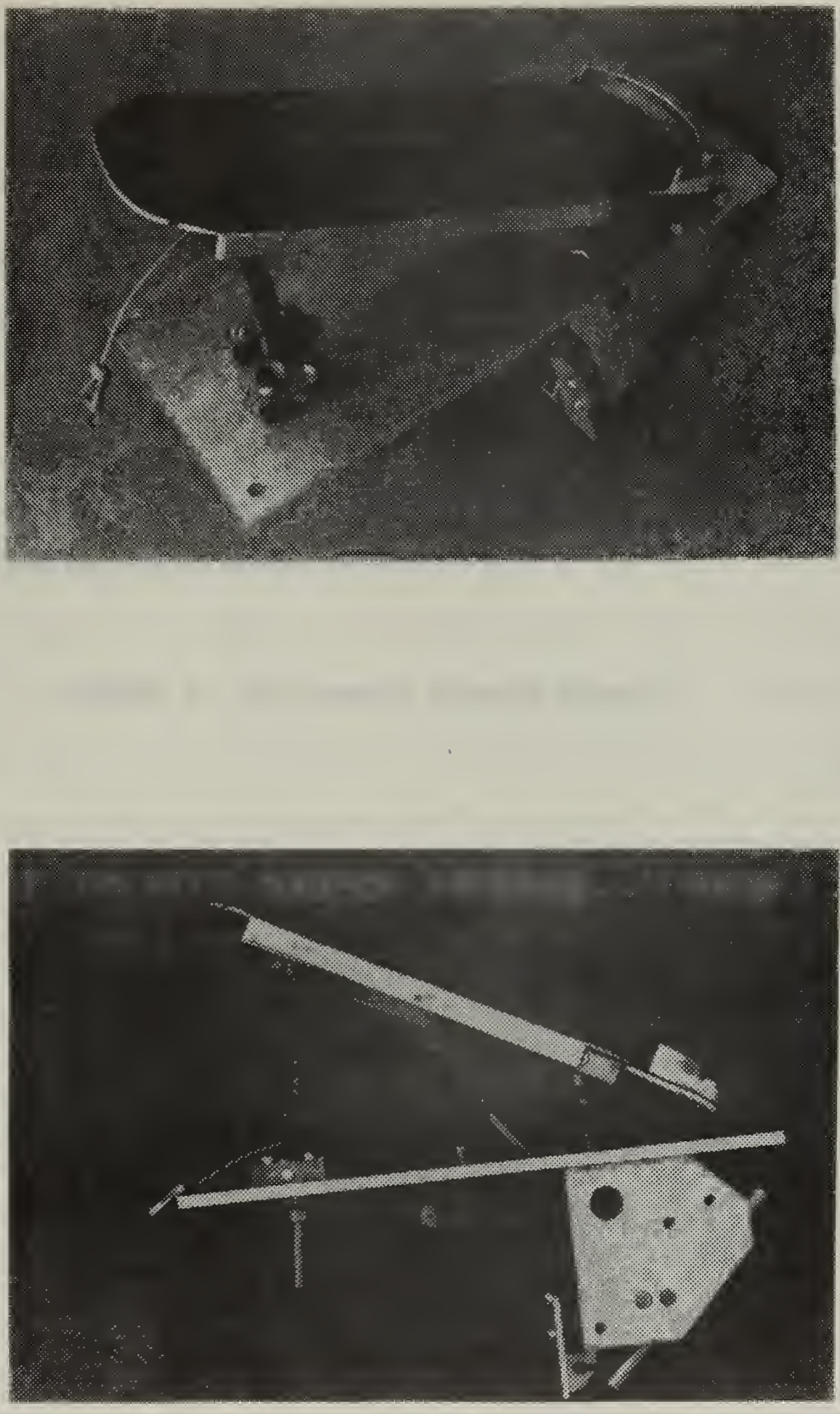


FIGURE 2. Two Views of Brake-Accelerator Pedal

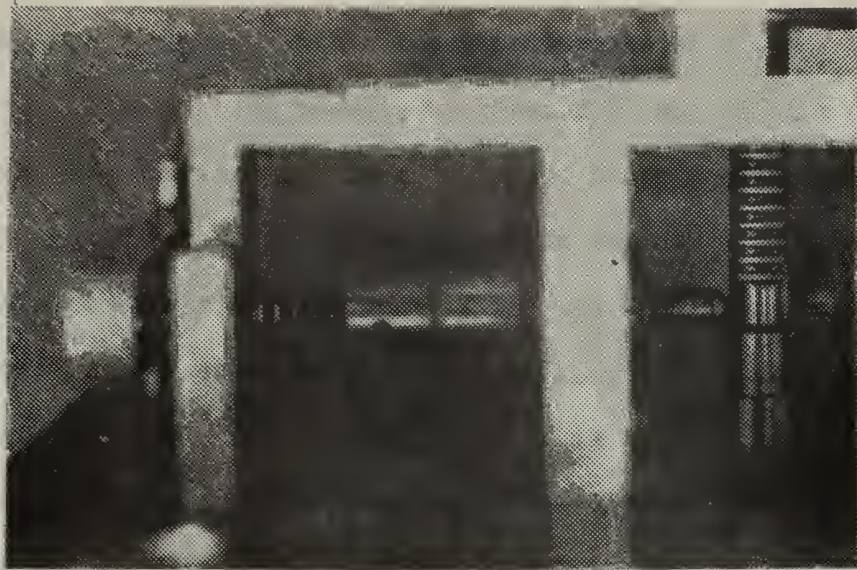


FIGURE 3. Accelerator Linkage Engaged.

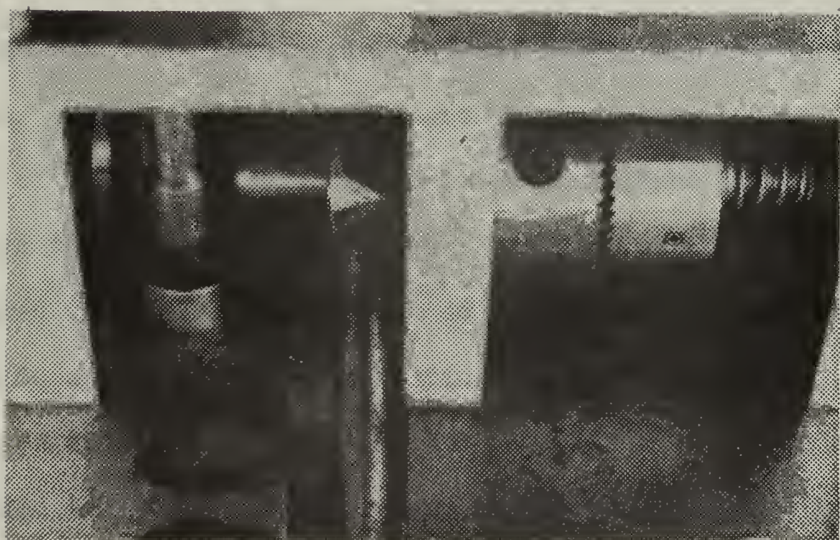
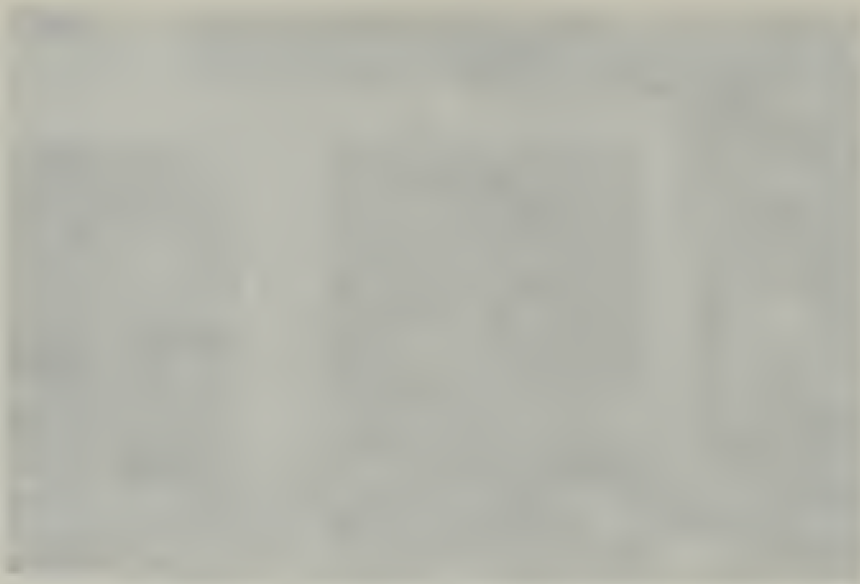


FIGURE 4. Accelerator Linkage Disengaged.



The pedal was installed with a rotational angle of 8$^{\circ}$, a compromise of the Toben [10] results of between 0$^{\circ}$ and 15$^{\circ}$ for obtaining the fastest reaction times. The 55$^{\circ}$ floor angle established by Toben [10] could not be directly applied in the car since the ankle angles become grossly different if 55$^{\circ}$ was used along with the considerably lower seat design. Nevertheless the ankle angles could be made compatible to the laboratory ankle angles, as follows. The floor angle in the car was fixed at 70$^{\circ}$ resulting in ankle angles ranging from 90$^{\circ}$ in the rear most seat position to 84$^{\circ}$ in the most forward seat position. The floor angle in the laboratory fixed at 55$^{\circ}$ resulted in ankle angles ranging from 90$^{\circ}$ in the rear most seat position to 76$^{\circ}$ in the most forward seat position (Figures 5 and 6). The range of the angles for the car, 84$^{\circ}$ - 90$^{\circ}$, is a subset of the range of these angles for the laboratory, 76$^{\circ}$ - 90$^{\circ}$, therefore the author feels it is a reasonable solution to use a floor angle of 70$^{\circ}$ in the car. In addition MacFarland and others [5] suggested the knee angle be greater than 90$^{\circ}$, with 135$^{\circ}$ or more preferred when pedal pressures under 20 pounds are required, and that ankle angles be 90$^{\circ}$ when holding the foot in position. The first of these suggestions is met in the car with a 70$^{\circ}$ floor angle and the second is met precisely or very closely depending on an individual subject's height and resultant seat position.

The conventional brake pedal was the original factory equipment of the Navy Sedan. It was a black, rubber, approximately rectangular surface (6 inches by 2 inches) hinged under the dash and protruding down to a position left of the accelerator-brake pedal. A plane through the center of the conventional brake pedal perpendicular

Diagram of Critical Angles in Car

A = Angle between seat back and horizontal plane*

B = Knee Angle*

C = Ankle Angle*

D = Floor Angle

* The two values represent the seat in the most forward and most rearward positions.

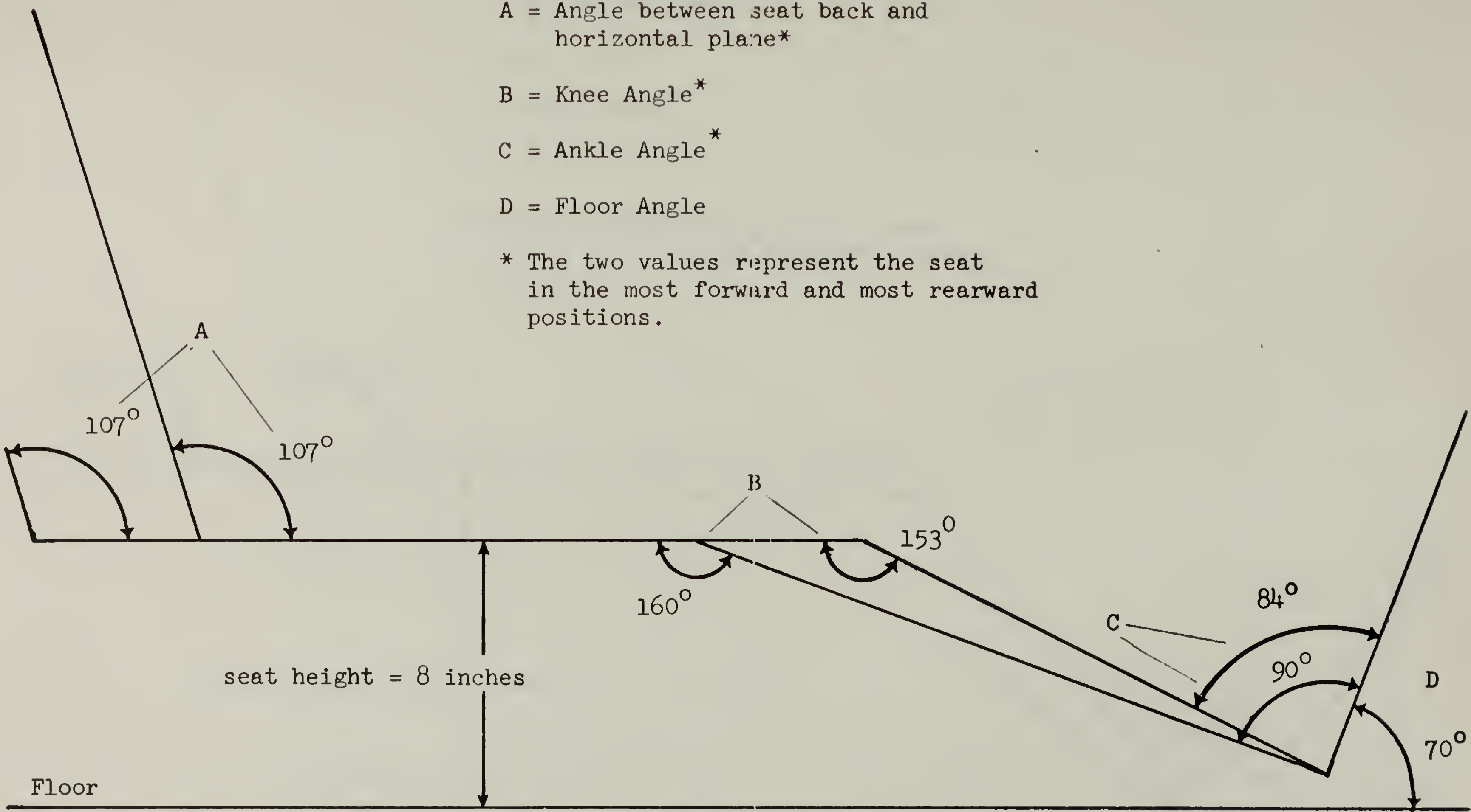



Figure 5

Diagram of Critical Angles in Laboratory Apparatus

A = Angle between seat back and
horizontal plane*

B = Knee Angle*

C = Ankle Angle*

D = Floor Angle

* The two values represent the seat in the most forward and most rearward positions.

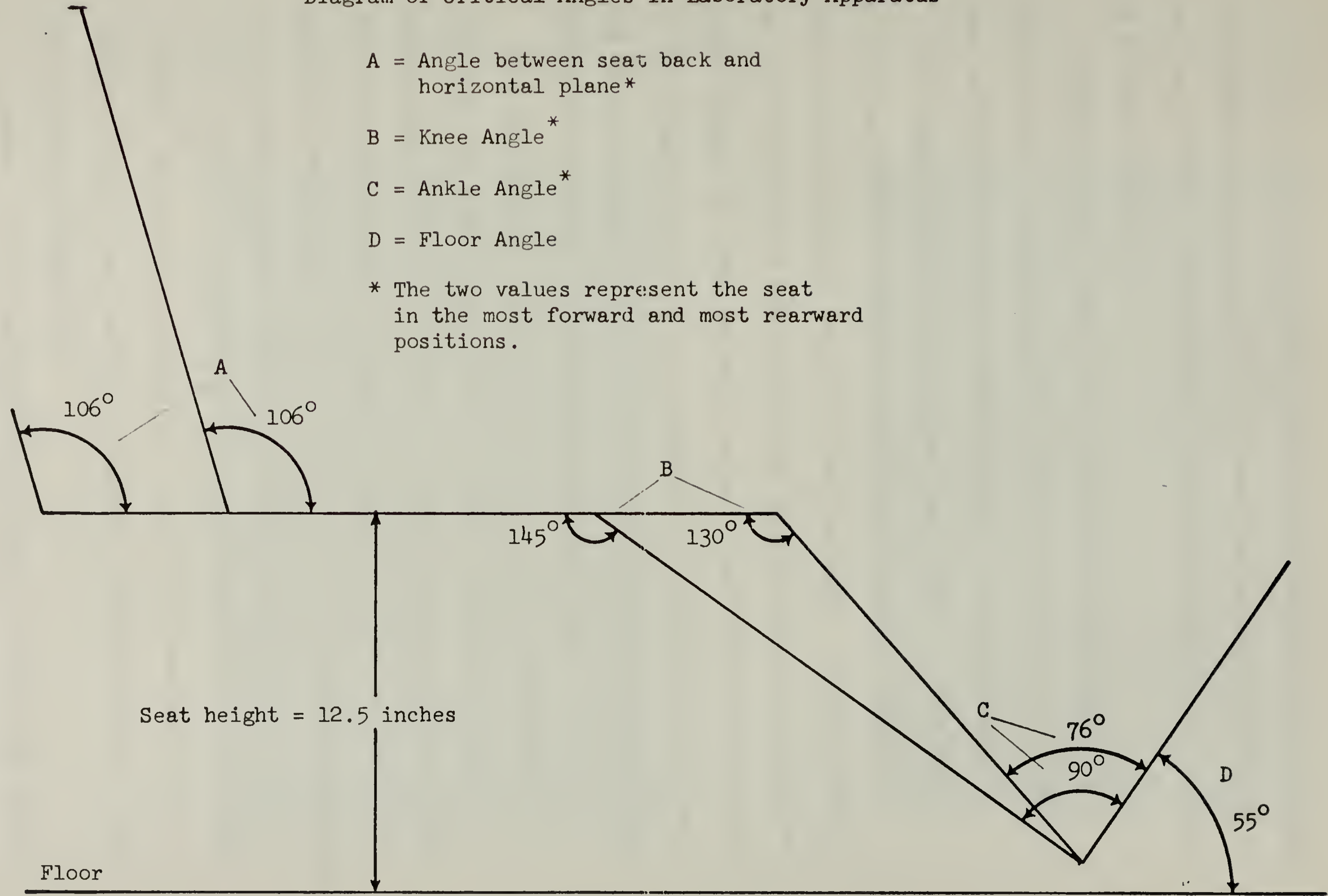



**Figure 6**

to the face of the accelerator-brake pedal would result in a straight-line distance in the plane of 7.6 inches from center to center or a vertical distance of 3 inches and a horizontal distance of 7 inches in the plane (Figure 7).

A 2900 Hz audible signal device was placed approximately $2\frac{1}{2}$ feet in front of the test subject pointed at his upper body. This tone provided the emergency braking signal in the experiment.

The timing circuitry and equipment was adapted so that the 12 volt car battery provided the power for timing and signal. A silent button activated the audio signal and timer. Either braking system when depressed one-eighth of an inch activated a microswitch which stopped the timer and audio signal. The time from the start of the stopping signal to the depression of the brake was recorded and visually displayed in microseconds on a sine wave counter-timer driven by 110 volts, obtained through the use of an invertor.

The microswitch on the brake-accelerator pedal was mounted in line with the braking shaft and was easily positioned (Figure 8). The microswitch for the conventional brake provided more difficulty. First, the brake pedal was pulled to the rear and to the left by a spring to remove excess motion. Second, the return of the brake pedal to its normal, somewhat unstable, position was blocked just short of that position to insure a positive consistent return to an exact location. By so doing a microswitch was mounted one-eighth inch forward of this fixed location providing a consistent point to trip the microswitch (Figure 9).

A number of safety precautions were taken to reduce the risk of an accident. First, a complete brake overhaul was performed and

FIGURE 7. Two Views of Installed Pedals.

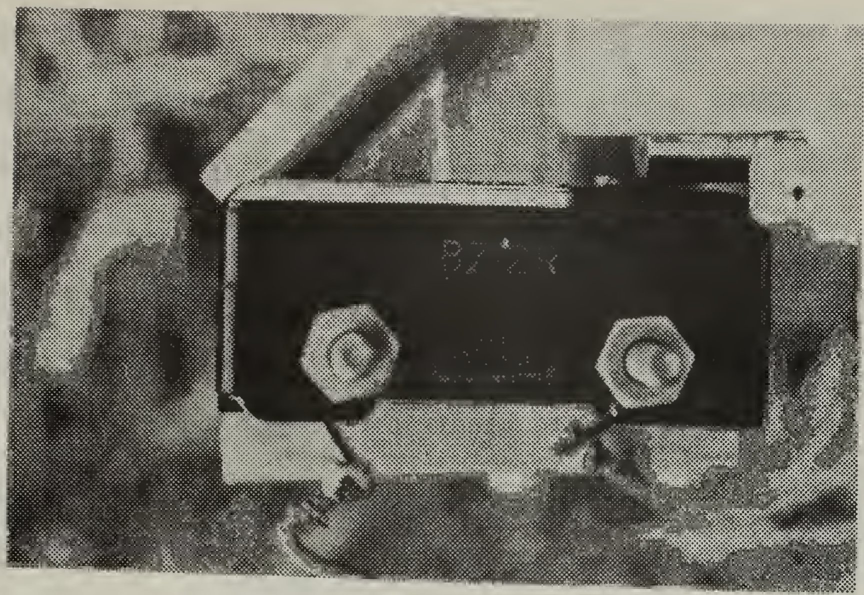


FIGURE 8. Microswitch for Brake-Accelerator Pedal.

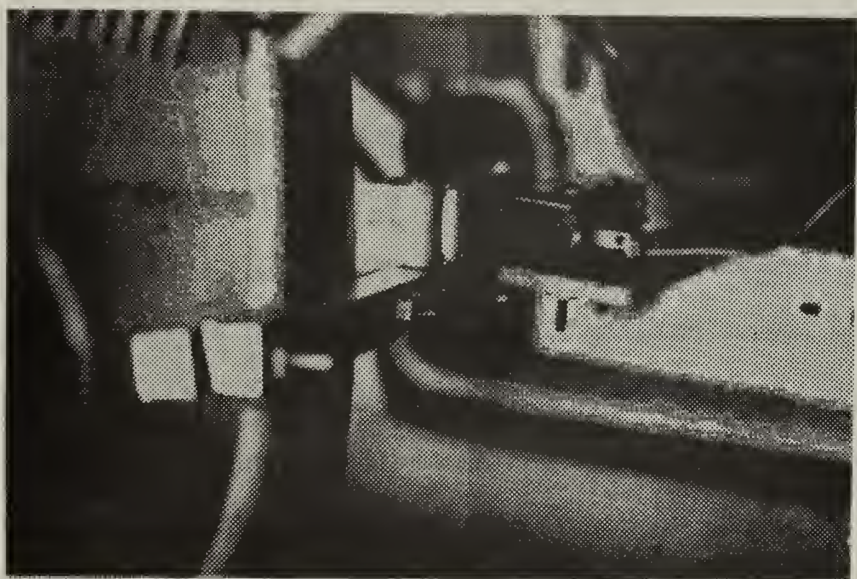


FIGURE 9. Microswitch for Conventional Brake Pedal.

new tires were put on the vehicle. Second, a shoulder harness was installed for the driver to supplement his seat belt. Third, all drivers were required to wear safety helmets. Fourth, no other vehicles were allowed on the test track and fifth, a speed of 40 miles per hour was never exceeded.

Other considerations in the design of this experiment should be mentioned. Seat tilt was found to be insignificant by Sullivan [8]; therefore, the minor differences in seat tilt were not considered in the experiment. The author has also assumed that seat height would not affect the results. Some weight is added to this assumption based on Davies and Watts [1] results where seat height was found not to be significant when testing 12 female subjects at seat heights of 17 inches and 12 inches.

## C. ENVIRONMENT

The experiment took place at the Laguna Seca Raceway, Ft. Ord, California, just outside the city of Monterey. The track is circular, 1.9 miles long, 30 foot wide and surfaced in asphalt (Figure 10). It consists of hills, curves and straightaways. No other vehicles were allowed on the track during testing and only track employees and personnel involved in the experiment were at the test site. All subjects were tested between 1300 hours and 1800 hours, except two who were tested mid-morning. The weather was excellent each of the four days on which testing was conducted. Each subject took about one hour to test. The author did all of the testing seated in the right rear of the car where he could observe the test equipment and the subject.

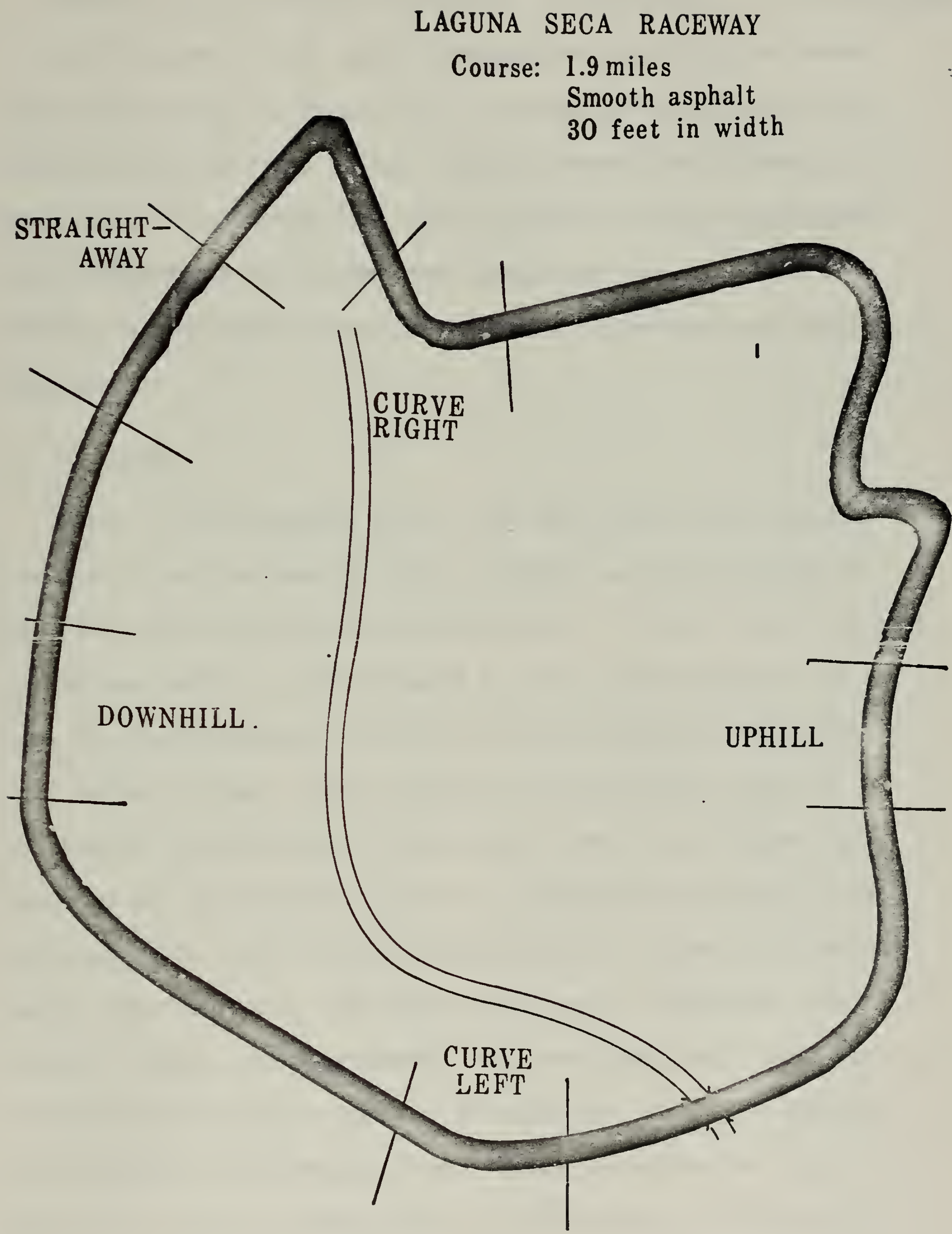

LAGUNA SECA RACEWAY
Course: 1.9 miles
Smooth asphalt
30 feet in width
STRAIGHT-
AWAY
CURVE
RIGHT
DOWNHILL.
UPHILL
CURVE
LEFT

Figure 10

## D. SUBJECTS

Thirteen male subjects volunteered to participate in this experiment. All were assigned to the Naval Postgraduate School and on active duty with the Navy or Marine Corps. Eleven of the subjects were between 28 and 32 years of age. The two others were 35 and 43 years old. All subjects had over 10 years of driving experience with conventional two and/or three pedal car systems. None of them had participated in any of the school's previous one pedal experiments.

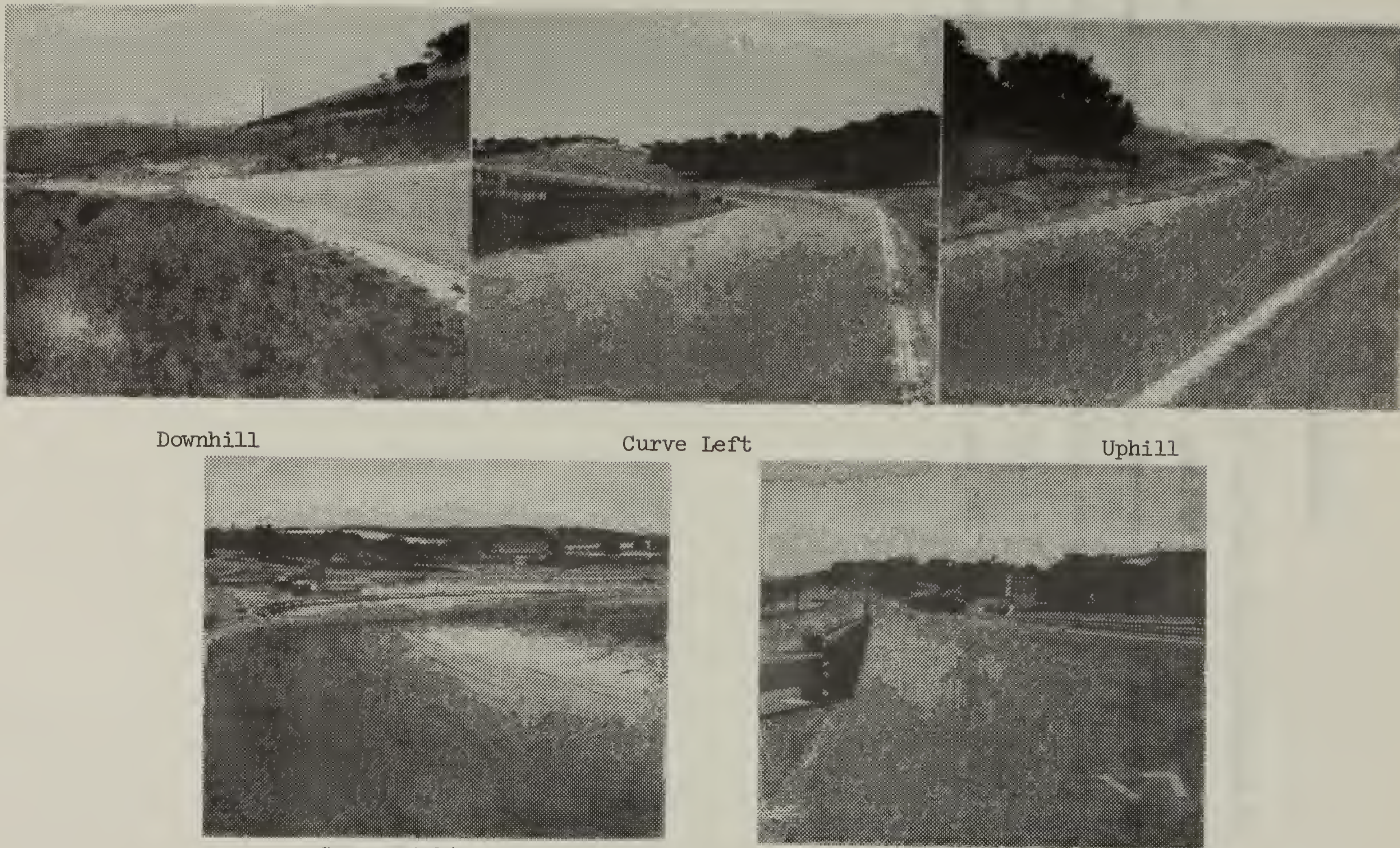
## E. PROCEDURE

Prior to the beginning of the test each subject was randomly assigned a test sequence of speeds, pedals, and road conditions. This was done to filter out learning effect. When a subject arrived at the test site he was thoroughly briefed on the operation of the car, the test equipment, the track and the procedure that would be used during the test. When the subject was satisfied that he understood the situation, he was asked to put on his helmet, get into the car and adjust his seat to a comfortable position, fasten his seat belts, start the car, and proceed at a speed of 25 miles per hour on the track. The first round was to familiarize the subject with the new environment, the test signal and pedals, as was the second lap at a speed of 35 miles per hour. The subject was informed of his reaction times during these practice laps to show him how fast he learned and to motivate him to do his best. If after this approximately four miles of driving the subject

appeared ready for testing, the random test sequence was begun. (In all but one case testing began after two rounds.)

Each subject was tested for each condition twice. This meant a subject made two laps at a given set of conditions, i.e., two laps at 35 miles per hour using the conventional brake pedal testing five road conditions on each lap. This resulted in a minimum of eight tested laps or approximately 16 miles of driving.

During each lap at least 10 signals were given, five were recorded at the predesignated locations for each road condition (Figures 10 and 11) and five or more were randomly given at different locations. The random signals were included to keep the subject continually alert to the brake pedal he was testing and to attempt to mask the location of the five road condition measurements.



Downhill

Curve Left

Uphill

Curve Right

Straightaway

FIGURE 11. Road Conditions.

## V. DATA REDUCTION

Each subject had a record of 40 reaction times consisting of two measures at each of two pedal combinations, two speeds and five road conditions. The two measures were averaged, providing a single value for each treatment combination. An overall average for each treatment combination is shown in Table I. In addition an average reaction time for each pedal type was calculated on each subject.

TABLE I

Mean Reaction Times
(in milliseconds)

| Road Condition | 25 MPH | | 35 MPH | |
|---|---|---|---|---|
| | Combined Pedal | Conventional Pedal | Combined Pedal | Conventional Pedal |
| Downhill | .283 | .473 | .300 | .470 |
| Curve Left | .303 | .474 | .298 | .472 |
| Uphill | .309 | .476 | .312 | .460 |
| Curve Right | .296 | .464 | .321 | .487 |
| Straightaway | .298 | .462 | .304 | .466 |

## VI. RESULTS

The following linear statistical model was assumed for the experiment.

$$T_{ijk\ell} = \mu + R_i + P_j + S_k + RP_{ij} + RS_{ik} + PS_{jk} + RPS_{ijk} + e_{\ell(ijk)}$$

where

$T_{ijk\ell}$ = brake reaction time

$\mu$ = the mean for all observations

$R_i$ = effect due to road condition (5 levels)

$P_j$ = effect due to pedal (2 levels)

$S_k$ = effect due to speeds (2 levels)

$e_{\ell(ijk)}$ = random experimental error.

$RP_{ij}$, $RS_{ik}$, $PS_{jk}$ and $RPS_{ijk}$ are interactions between factors.

A three-way, fixed effects analysis of variance was the method used to test the null hypothesis that there is no difference among the effects of road condition, pedal and speed. The alternate hypothesis was that there is a difference among the effects. The analysis of variance showed a significant difference among the pedals but neither speed, road condition nor interactions were significant. (Table II).

A comparison of the means of the AAA reaction times obtained by Sullivan [8] and the conventional brake pedal reaction times in this experiment was made by a student's t-test for difference between two means assuming homogeneity of variance [Winer 1962]. Likewise a test for differences of means in the two experiments was

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

TABLE II

Three Way ANOVA

| Treatment | Degrees of Freedom | Mean Square | F Value |
|---|---|---|---|
| Road Condition (R) | 4 | 996.50 | .46 |
| Pedal Type (P) | 1 | 1,837,080.86 | 854.52* |
| Speed (S) | 1 | 1,711.10 | .80 |
| R x P | 4 | 984.89 | .46 |
| R x S | 4 | 1,916.80 | .89 |
| P x S | 1 | 1,134.04 | .53 |
| R x P x S | 4 | 370.16 | .17 |
| Error | 240 | 2,149.85 | |
| Total | 259 | 2,372,962.90 | |

*Significant at p = 0.01

[illegible]

conducted on the reaction time means for the combined brake-accelerator pedal. In the first case, no significant difference could be shown. In the second case, the difference in means was significant at the .01 level (Table III).

The test statistic was

$$t = \frac{(\bar{X}_R - \bar{X}_L) - (\mu_R - \mu_L)}{S_p^2 \left(\frac{1}{n_R} + \frac{1}{n_L}\right)} \quad \text{where } (\mu_R - \mu_L) = 0$$

where the subscripts R and L represents road and laboratory, respectively.

## TABLE III

Student's t-test for Difference Between Means

Conventional Brake Pedal

| Treatment | Sample Size | Sample Variance | Sample Mean |
|---|---|---|---|
| Road | 13 | .002025 | .470 |
| Laboratory | 55 | .002500 | .468 |

Pooled Variance = 0.002414
t = 0.132

Brake Accelerator Pedal

| Treatment | Sample Size | Sample Variance | Sample Mean |
|---|---|---|---|
| Road | 13 | .001156 | .302 |
| Laboratory | 55 | .000900 | .259 |

Pooled Variance = 0.000946
t = 4.53*

* Significant at p = 0.01

## VII. DISCUSSION AND CONCLUSION

Road conditions and moderate speeds do not appear to affect brake reaction times in this experiment. As previously shown, the single brake-accelerator pedal is highly significant in reducing brake reaction time, attributable mainly to the lack of foot movement with this design. This decrease in brake reaction time (36 per cent in this experiment) will result in a reduction in stopping distance of 15 feet when traveling at 60 miles per hour. This could be a critical factor in a potential accident situation.

The lack of difference between the result of the AAA reaction time found by Sullivan [8] and this experiment appear quite reasonable. The average number of years of driving experience among the 13 subjects of this experiment was fifteen and the author would expect a similar figure for Sullivan's 55 subjects. With this extensive experience with two and three pedal cars the author would not expect large differences in reaction times regardless of the environment, laboratory or road, since the braking reflex is well grooved. In the case of the brake-accelerator pedal a difference between the reaction times of the laboratory and road was apparent and appeared logical. First, the natural reaction of every driver in a car is to brake in a conventional way when a signal is given. The driver must fight this learned reaction, a result of years of experience. Second, the new braking system on the road is in competition with the requirement to maintain speed and handle the car whereas in the laboratory the subject only needed to concentrate

on the signal. Thirdly, many of the subjects indicated they do not usually drive with their entire foot in complete contact with the face of the accelerator pedal. Since this is required when attempting to minimize reaction time with the brake-accelerator pedal it produced a slightly uncomfortable sensation for some subjects. In one case, a subject complained of getting a muscle cramp in the lower leg. It appears that although an optimal design can be made for speed of reaction, discomfort may require some modification in the single pedal design. In addition women's shoes may present a design problem.

During the course of the experiment moving from one pedal to another sometimes required several practice signals. This was done as required to insure that the subject was properly orientated to his task.

## VIII. RECOMENDATIONS

The author strongly recommends continued research in the design and application of a single brake-accelerator pedal. Women and their footwear should be introduced into the study to see if the system still outperforms the conventional brake system without undue complication. The extensive Congressional interest in automobile safety should provide an excellent opportunity to generate research support to continue this program. It is a viable concept that should be throughly researched and developed for the benefit of all drivers.

[illegible]

[illegible]

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**13. ABSTRACT**

This experiment was a road test of a combined brake-accelerator pedal conducted at Laguna Seca Raceway, Monterey, California. One purpose was to compare the results of the road test with previous results of laboratory experiments at the Naval Postgraduate School, Monterey, California. Another purpose was to investigate the effect of moderate speeds and road conditions on brake reaction times.

A total of 13 test subjects were used, from 28 to 43 years of age, each contributing 40 reaction times during approximately 16 miles of driving. The combined brake pedal and the conventional brake pedal resulted in average reaction times of .302 seconds and .470 seconds, respectively, significant at the .01 level. Compared to the most recent laboratory tests the conventional pedal results were almost identical. Results with the combined brake-accelerator pedals were significantly slower. Although slower, the savings in brake reaction time during the road test of .168 second is a 36% reaction time savings which, translated into distance, is approximately 15 feet at 60 miles per hour. Speeds and road conditions were not significant at the .01 level of significance.

| KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Road test, Brake-Accelerator Pedal | | | | | | |
| Combined Brake-Accelerator Pedal | | | | | | |
| Brake-Accelerator Pedal | | | | | | |
| Braking Reaction Time | | | | | | |
| Braking Distance; Reduction in | | | | | | |
| Emergency Braking | | | | | | |
| One-Pedal Automobile System | | | | | | |
| Conventional Brake Pedal | | | | | | |
| Braking, Automobile | | | | | | |
| Speed, Effect on Braking | | | | | | |
| Road Condition, Effect on Braking | | | | | | |
| Single Pedal Automobile System | | | | | | |

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